MULTIMEDIA UNIVERSITY

**STUDENT ID NO**

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# MULTIMEDIA UNIVERSITY

# FINAL EXAMINATION

**TRIMESTER 2, 2018/2019**

## ERT3016 – ROBOTICS

( RE )

13 MARCH 2019
2.30 p.m. - 4.30 p.m.
( 2 Hours )

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**INSTRUCTIONS TO STUDENTS**

1. This Question paper consists of 7 pages including cover page with 5 Questions only. DH-parameter procedures are included in Appendix.

2. Attempt **ALL** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please write all your answers in the Answer Booklet provided.

## Question 1

a) Define the three *basic laws* for robots.

**[3 marks]**

b) List down **FIVE** major components of a robot. Briefly explain the function for each of them.

**[10 marks]**

c) A car manufacturing company is planning to set up a semi-automated car assembling plant in Malaysia. They are seeking for your advice in the selection of the type of drive system for their articulated robotic arm. What would be your advice?

**[5 marks]**

d) Give two examples of robot applications in the industry.

**[2 marks]**

**Continued...**

## Question 2

a) Consider the robotic tool shown in Fig. Q2. Suppose we yaw the tool by $\pi/2$ about $f^1$, then pitch the tool by $-\pi/2$ about $f^2$, and finally roll the tool by $\pi$ about $f^3$.

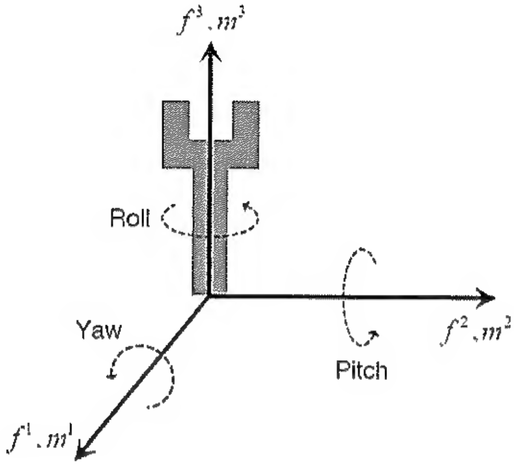


Fig. Q2

i) Find the transformation matrix, T, which maps tool coordinates, M, following the sequence of rotations.

**[8 marks]**

ii) Find the location of the tool-tip, p, in wrist coordinates, F, following the sequence of rotations. Given that the tool-tip coordinates in terms of the tool frame are $[p]^M = [0 \quad 1.2 \quad 0.6]^T$.

**[4 marks]**

b) A homogeneous transformation matrix that maps a mobile frame coordinates M into a fixed frame coordinates F is given below.

$$T = \begin{bmatrix} 0.2588 & 0 & 0.8666 & 12 \\ 0.8666 & 0 & -0.2588 & -5 \\ 0 & 1 & 0 & 8 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

i) Find the inverse homogeneous transformation matrix of T. **[5 marks]**

ii) Find $[f^3]^M$. **[3 marks]**

**Continued...**

## Question 3

A manipulator with three degrees of freedom is shown in Fig. Q3. The first two joint axes are revolute joints, while the third is a prismatic joint.

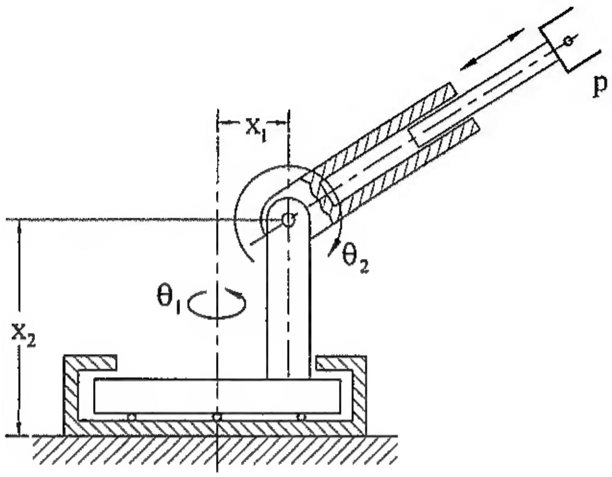


Fig. Q3

a) Draw the link-coordinate diagram of this robot. Add all the necessary kinematic parameters and label them clearly based on Denavit-Hartenberg algorithm. (Refer to table below for its home position).

**[6 marks]**

b) Fill in the kinematic parameters in the following table.

| Axis | θ | d | a | α | Home |
|---|---|---|---|---|---|
| 1 | | | | | 0 |
| 2 | | | 0 | | $\pi/2$ |
| 3 | $-\pi/2$ | | | | 10 |

**[5 marks]**

c) Find the arm matrix $T_{base}^{tool}(q)$ at home position.

**[9 marks]**

**Continued...**

## Question 4

The direct kinematics equations for a four-axis robot are given below.

$$T_0^1 = \begin{bmatrix} -S_1 & 0 & C_1 & 0 \\ C_1 & 0 & S_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \qquad T_1^2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & q_2 \\ 0 & 0 & 0 & 1 \end{bmatrix};$$

$$T_2^3 = \begin{bmatrix} -S_3 & 0 & -C_3 & 0 \\ C_3 & 0 & -S_3 & 0 \\ 0 & -1 & 0 & d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \qquad T_3^4 = \begin{bmatrix} C_4 & 0 & S_4 & S_4a_4 \\ S_4 & 0 & -C_4 & -C_4a_4 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix};$$

a) Find the general arm equation, $T_0^4(q)$.

**[12 marks]**

b) With a given tool pose $T_0^4 = \begin{bmatrix} 0 & 1 & 0 & 43.3 \\ 1 & 0 & 0 & 25 \\ 0 & 0 & 1 & 15 \\ 0 & 0 & 0 & 1 \end{bmatrix}$, solve the inverse kinematics equations to find all the joint variables $q_n$ where $n = 1, 2, 3, 4$.

**[8 marks]**

## Question 5

a) A robotic workstation, with parts A and B, is as shown in Fig. Q5. Given that the centroid of part A has coordinates $\begin{bmatrix}2 & 12 & 5\end{bmatrix}^T$ and the centroid of part B has coordinates $\begin{bmatrix}7 & 3 & 5\end{bmatrix}^T$.

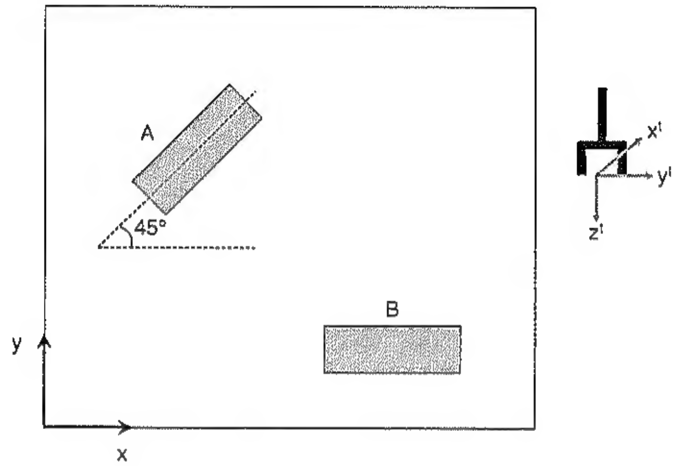


Fig. Q5

i) Find the arm matrix value $T_{base}^{pick}$ needed to pick up part A from above by grasping it in the middle of the long sides.

**[4 marks]**

ii) Find the arm matrix value $T_{base}^{pick}$ needed to pick up part B from above by grasping it in the middle of the long sides.

**[3 marks]**

iii) Find the arm matrix value $T_{base}^{place}$ needed to place part B on top of part A aligning the centroids and the major axes.

**[3 marks]**

b) The waist of a four-axis robot is to go from initial angle of $90^\circ$ to an end position of $147^\circ$ in 2.3 seconds. By using a third-order polynomial in joint-space, calculate the joint angle and velocity at the time 1.9 seconds. Assume the robot starts at rest and all joints stop at end point.

**[10 marks]**

**Continued ...**

## Appendix

Procedure to DH-Parameter

1. Number the joints from 1 to $n$ starting at the base and ending with the tool yaw, pitch and roll, in that order.
2. Assign a right-handed orthonormal coordinate frame $L_0$ to the robot base, making sure that $z^0$ aligns with the axis of joint 1. Set $k$ =1.
3. Align $z^k$ with the axis of joint $k$ + 1.
4. Locate the origin of $L_k$ at the intersection of the $z^k$ and $z^{k-1}$ axes. If they do not intersect, use the intersection of $z^k$ with a common normal between $z^k$ and $z^{k-1}$.
5. Select $x^k$ to be orthogonal to both $z^k$ and $z^{k-1}$. If $z^k$ and $z^{k-1}$ are parallel, point $x^k$ away from $z^{k-1}$.
6. Select $y^k$ to form right-handed orthonormal coordinate frame $L_k$ and set $k$ = $k$+1. If $k<n$, go to step 3; else continue.
7. Set the origin of $L_n$ at the tool tip. Align $z^n$ with the approach vector, $y^n$ with the sliding vector
   and $x^n$ with the normal vector of the tool. Set $k$ =1.
8. Locate point $b^k$ at the intersection of the $x^k$ and $z^{k-1}$ axes. If they do not intersect, use the intersection of $x^k$ with a common normal between $x^k$ and $z^{k-1}$.
9. Compute $\theta_k$ as the angle of rotation from $x^{k-1}$ to $x^k$ measured about $z^{k-1}$.
10. Compute $d_k$ as the distance from the origin of frame $L_{k-1}$ to point $b^k$ measured along $z^{k-1}$.
11. Compute $a_k$ as the distance from the point $b^k$ to the origin of frame $L_k$ measured along $x^k$.
12. Compute $\alpha_k$ as the angle of rotation from $z^{k-1}$ to $z^k$ measured about $x^k$.
13. Set $k = k$ +1. If $k \leq n$, go to step 8; else stop.

Generic DH-Transformation Matrix

$$T_{k-1}^{k} = \begin{bmatrix} C\theta_k & -S\theta_k C\alpha_k & S\theta_k S\alpha_k & a_k C\theta_k \\ S\theta_k & C\theta_k C\alpha_k & -C\theta_k S\alpha_k & a_k S\theta_k \\ 0 & S\alpha_k & C\alpha_k & d_k \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

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